Gravity and Strings

One appealing feature of string theory is that it provides a theory of quantum gravity. Gravity and Strings is a self-contained, pedagogical exposition of this theory, its foundations, and its basic results.

In Part I, the foundations are traced back to the very early special-relativistic field theories of gravity, showing how such theories, which are associated with the concept of the graviton, lead to general relativity. Gauge theories of gravity are then discussed and used to introduce supergravity theories.

Part II covers some of the most interesting solutions of general relativity and its generalizations. These include Schwarzschild and Reissner-Nordström black holes, the Taub-NUT solution, gravitational instantons, and gravitational waves. Kaluza-Klein theories and the uses of residual supersymmetries are discussed in detail.

Part III presents string theory from the effective-action point of view, using the results found earlier in the book as background. The supergravity theories associated with superstrings and M theory are thoroughly studied, and used to describe dualities and classical solutions related to non-pertubative states of these theories. A brief account of extreme black-hole entropy calculations is also given.

This unique book will be useful as a reference for graduate students and researchers, as well as a complementary textbook for courses on gravity, supergravity, and string theory.

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Gravity and Strings

TOMÁS ORTÍN

Spanish Research Council and Universidad Autónoma de Madrid (CSIC)
To Marimar, Diego, and Tomás, the sweet strings that tie me to the real world
Contents

Preface

Part I Introduction to gravity and supergravity

1 Differential geometry

1.1 World tensors
1.2 Affinely connected spacetimes
1.3 Metric spaces
  1.3.1 Riemann–Cartan spacetime $U_d$
  1.3.2 Riemann spacetime $V_d$
1.4 Tangent space
  1.4.1 Weitzenböck spacetime $A_d$
1.5 Killing vectors
1.6 Duality operations
1.7 Differential forms and integration
1.8 Extrinsic geometry

2 Noether's theorems

2.1 Equations of motion
2.2 Noether's theorems
2.3 Conserved charges
2.4 The special-relativistic energy–momentum tensor
  2.4.1 Conservation of angular momentum
  2.4.2 Dilatations
  2.4.3 Rosenfeld's energy–momentum tensor
2.5 The Noether method

3 A perturbative introduction to general relativity

3.1 Scalar SRFTs of gravity
3.1 Scalar gravity coupled to matter
3.1.1 Scalar gravity coupled to matter
3.1.2 The action for a relativistic massive point-particle
3.1.3 The massive point-particle coupled to scalar gravity
3.1.4 The action for a massless point-particle
3.1.5 The massless point-particle coupled to scalar gravity
3.1.6 Self-coupled scalar gravity
3.1.7 The geometrical Einstein–Fokker theory

3.2 Gravity as a self-consistent massless spin-2 SRFT
3.2.1 Gauge invariance, gauge identities, and charge conservation in the SRFT of a spin-1 particle
3.2.2 Gauge invariance, gauge identities, and charge conservation in the SRFT of a spin-2 particle
3.2.3 Coupling to matter
3.2.4 The consistency problem
3.2.5 The Noether method for gravity
3.2.6 Properties of the gravitational energy–momentum tensor \( T^{(0),\mu\nu}_{GR} \)
3.2.7 Deser’s argument

3.3 General relativity

3.4 The Fierz–Pauli theory in a curved background
3.4.1 Linearized gravity
3.4.2 Massless spin-2 particles in curved backgrounds
3.4.3 Self-consistency

3.5 Final comments

4 Action principles for gravity
4.1 The Einstein–Hilbert action
4.1.1 Equations of motion
4.1.2 Gauge identity and Noether current
4.1.3 Coupling to matter
4.2 The Einstein–Hilbert action in different conformal frames
4.3 The first-order (Palatini) formalism
4.3.1 The purely affine theory
4.4 The Cartan–Sciama–Kibble theory
4.4.1 The coupling of gravity to fermions
4.4.2 The coupling to torsion: the CSK theory
4.4.3 Gauge identities and Noether currents
4.4.4 The first-order Vielbein formalism
4.5 Gravity as a gauge theory
4.6 Teleparallelism
4.6.1 The linearized limit

5 N = 1, 2, d = 4 supergravities
5.1 Gauging \( N = 1, d = 4 \) superalgebras
5.2 \( N = 1, d = 4 \) (Poincaré) supergravity
5.2.1 Local supersymmetry algebra
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3</td>
<td>$N = 1, d = 4$ AdS supergravity</td>
<td>159</td>
</tr>
<tr>
<td></td>
<td>5.3.1 Local supersymmetry algebra</td>
<td>160</td>
</tr>
<tr>
<td>5.4</td>
<td>Extended supersymmetry algebras</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>5.4.1 Central extensions</td>
<td>163</td>
</tr>
<tr>
<td>5.5</td>
<td>$N = 2, d = 4$ (Poincaré) supergravity</td>
<td>164</td>
</tr>
<tr>
<td></td>
<td>5.5.1 The local supersymmetry algebra</td>
<td>167</td>
</tr>
<tr>
<td>5.6</td>
<td>$N = 2, d = 4$ “gauged” (AdS) supergravity</td>
<td>167</td>
</tr>
<tr>
<td></td>
<td>5.6.1 The local supersymmetry algebra</td>
<td>169</td>
</tr>
<tr>
<td></td>
<td>5.7 Proofs of some identities</td>
<td>169</td>
</tr>
<tr>
<td>6</td>
<td>Conserved charges in general relativity</td>
<td>171</td>
</tr>
<tr>
<td></td>
<td>6.1 The traditional approach</td>
<td>172</td>
</tr>
<tr>
<td></td>
<td>6.1.1 The Landau–Lifshitz pseudotensor</td>
<td>174</td>
</tr>
<tr>
<td></td>
<td>6.1.2 The Abbott–Deser approach</td>
<td>176</td>
</tr>
<tr>
<td></td>
<td>6.2 The Noether approach</td>
<td>179</td>
</tr>
<tr>
<td></td>
<td>6.3 The positive-energy theorem</td>
<td>180</td>
</tr>
<tr>
<td>Part II</td>
<td>Gravitating point-particles</td>
<td>185</td>
</tr>
<tr>
<td>7</td>
<td>The Schwarzschild black hole</td>
<td>187</td>
</tr>
<tr>
<td></td>
<td>7.1 Schwarzschild’s solution</td>
<td>188</td>
</tr>
<tr>
<td></td>
<td>7.1.1 General properties</td>
<td>189</td>
</tr>
<tr>
<td></td>
<td>7.2 Sources for Schwarzschild’s solution</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>7.3 Thermodynamics</td>
<td>202</td>
</tr>
<tr>
<td></td>
<td>7.4 The Euclidean path-integral approach</td>
<td>208</td>
</tr>
<tr>
<td></td>
<td>7.4.1 The Euclidean Schwarzschild solution</td>
<td>209</td>
</tr>
<tr>
<td></td>
<td>7.4.2 The boundary terms</td>
<td>210</td>
</tr>
<tr>
<td></td>
<td>7.5 Higher-dimensional Schwarzschild metrics</td>
<td>211</td>
</tr>
<tr>
<td></td>
<td>7.5.1 Thermodynamics</td>
<td>212</td>
</tr>
<tr>
<td>8</td>
<td>The Reissner–Nordström black hole</td>
<td>213</td>
</tr>
<tr>
<td></td>
<td>8.1 Coupling a scalar field to gravity and no-hair theorems</td>
<td>214</td>
</tr>
<tr>
<td></td>
<td>8.2 The Einstein–Maxwell system</td>
<td>218</td>
</tr>
<tr>
<td></td>
<td>8.2.1 Electric charge</td>
<td>221</td>
</tr>
<tr>
<td></td>
<td>8.2.2 Massive electrodynamics</td>
<td>225</td>
</tr>
<tr>
<td></td>
<td>8.3 The electric Reissner–Nordström solution</td>
<td>227</td>
</tr>
<tr>
<td></td>
<td>8.4 The sources of the electric RN black hole</td>
<td>238</td>
</tr>
<tr>
<td></td>
<td>8.5 Thermodynamics of RN black holes</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>8.6 The Euclidean electric RN solution and its action</td>
<td>242</td>
</tr>
<tr>
<td></td>
<td>8.7 Electric–magnetic duality</td>
<td>245</td>
</tr>
<tr>
<td></td>
<td>8.7.1 Poincaré duality</td>
<td>248</td>
</tr>
<tr>
<td></td>
<td>8.7.2 Magnetic charge: the Dirac monopole and the Dirac quantization condition</td>
<td>248</td>
</tr>
<tr>
<td></td>
<td>8.7.3 The Wu–Yang monopole</td>
<td>254</td>
</tr>
</tbody>
</table>
Contents

8.7.4 Dyons and the DSZ charge-quantization condition 256
8.7.5 Duality in massive electrodynamics 258
8.8 Magnetic and dyonic RN black holes 259
8.9 Higher-dimensional RN solutions 262

9 The Taub–NUT solution 267
9.1 The Taub–NUT solution 268
9.2 The Euclidean Taub–NUT solution 271
9.2.1 Self-dual gravitational instantons 272
9.2.2 The BPST instanton 274
9.2.3 Instantons and monopoles 275
9.2.4 The BPST instanton and the KK monopole 277
9.2.5 Bianchi IX gravitational instantons 277
9.3 Charged Taub–NUT solutions and IWP solutions 279

10 Gravitational pp-waves 282
10.1 pp-Waves 282
10.1.1 Hpp-waves 283
10.2 Four-dimensional pp-wave solutions 285
10.2.1 Higher-dimensional pp-waves 287
10.3 Sources: the AS shock wave 287

11 The Kaluza–Klein black hole 290
11.1 Classical and quantum mechanics on $\mathbb{R}^{1,3} \times S^1$ 291
11.2 KK dimensional reduction on a circle $S^1$ 296
11.2.1 The Scherk–Schwarz formalism 299
11.2.2 Newton’s constant and masses 303
11.2.3 KK reduction of sources: the massless particle 306
11.2.4 Electric–magnetic duality and the KK action 310
11.2.5 Reduction of the Einstein–Maxwell action and $N = 1, d = 5$ SUGRA 313
11.3 KK reduction and oxidation of solutions 316
11.3.1 ERN black holes 317
11.3.2 Dimensional reduction of the AS shock wave: the extreme electric KK black hole 321
11.3.3 Non-extreme Schwarzschild and RN black holes 323
11.3.4 Simple KK solution-generating techniques 326
11.4 Toroidal (Abelian) dimensional reduction 331
11.4.1 The 2-torus and the modular group 336
11.4.2 Masses, charges and Newton’s constant 338
11.5 Generalized dimensional reduction 339
11.5.1 Example 1: a real scalar 341
11.5.2 Example 2: a complex scalar 345
11.5.3 Example 3: an SL(2, $\mathbb{R}$)/SO(2) $\sigma$-model 346
11.5.4 Example 4: Wilson lines and GDR 347
## Contents

11.6 Orbifold compactification 348

12 Dilaton and dilaton/axion black holes 349
12.1 Dilaton black holes: the $a$-model 350
12.1.1 The $a$-model solutions in four dimensions 354
12.2 Dilaton/axion black holes 358
12.2.1 The general SWIP solution 363
12.2.2 Supersymmetric SWIP solutions 365
12.2.3 Duality properties of the SWIP solutions 366
12.2.4 $N = 2, d = 4$ SUGRA solutions 367

13 Unbroken supersymmetry 369
13.1 Vacuum and residual symmetries 370
13.2 Supersymmetric vacua and residual (unbroken) supersymmetries 373
13.2.1 Covariant Lie derivatives 375
13.2.2 Calculation of supersymmetry algebras 378
13.3 $N = 1, 2, d = 4$ vacuum supersymmetry algebras 379
13.3.1 The Killing-spinor integrability condition 382
13.3.2 The vacua of $N = 1, d = 4$ Poincaré supergravity 383
13.3.3 The vacua of $N = 1, d = 4$ AdS$_4$ supergravity 384
13.3.4 The vacua of $N = 2, d = 4$ Poincaré supergravity 386
13.3.5 The vacua of $N = 2, d = 4$ AdS supergravity 389
13.4 The vacua of $d = 5, 6$ supergravities with eight supercharges 390
13.4.1 $N = (1, 0), d = 6$ supergravity 390
13.4.2 $N = 1, d = 5$ supergravity 391
13.4.3 Relation to the $N = 2, d = 4$ vacua 393
13.5 Partially supersymmetric solutions 394
13.5.1 Partially unbroken supersymmetry, supersymmetry bounds, and the superalgebra 395
13.5.2 Examples 398

Part III Gravitating extended objects of string theory 403

14 String theory 405
14.1 Strings 409
14.1.1 Superstrings 412
14.1.2 Green–Schwarz actions 415
14.2 Quantum theories of strings 417
14.2.1 Quantization of free-bosonic-string theories 417
14.2.2 Quantization of free-fermionic-string theories 422
14.2.3 D-Branes and O-planes in superstring theories 424
14.2.4 String interactions 425
14.3 Compactification on $S^1$: T duality and D-branes 426
14.3.1 Closed bosonic strings on $S^1$ 426
14.3.2 Open bosonic strings on $S^1$ and D-branes 427
14.3.3 Superstrings on $S^1$ 429

15 The string effective action and T duality 430
15.1 Effective actions and background fields 430
15.1.1 The D-brane effective action 434
15.2 T duality and background fields: Buscher’s rules 435
15.2.1 T duality in the bosonic-string effective action 436
15.2.2 T duality in the bosonic-string worldsheet action 439
15.2.3 T duality in the bosonic D$p$-brane effective action 443
15.3 Example: the fundamental string (F1) 445

16 From eleven to four dimensions 447
16.1 Dimensional reduction from $d = 11$ to $d = 10$ 449
16.1.1 11-dimensional supergravity 449
16.1.2 Reduction of the bosonic sector 452
16.1.3 Magnetic potentials 458
16.1.4 Reduction of fermions and the supersymmetry rules 461
16.2 Romans’ massive $N = 2A$, $d = 10$ supergravity 463
16.3 Further reduction of $N = 2A$, $d = 10$ SUEGRA to nine dimensions 466
16.3.1 Dimensional reduction of the bosonic RR sector 466
16.3.2 Dimensional reduction of fermions and supersymmetry rules 467
16.4 The effective-field theory of the heterotic string 469
16.5 Toroidal compactification of the heterotic string 471
16.5.1 Reduction of the action of pure $N = 1$, $d = 10$ supergravity 471
16.5.2 Reduction of the fermions and supersymmetry rules of $N = 1$, $d = 10$ SUGRA 475
16.5.3 The truncation to pure supergravity 477
16.5.4 Reduction with additional U(1) vector fields 478
16.5.5 Trading the KR 2-form for its dual 480
16.6 T duality, compactification, and supersymmetry 482

17 The type-IIB superstring and type-II T duality 485
17.1 $N = 2B$, $d = 10$ supergravity in the string frame 486
17.1.1 Magnetic potentials 487
17.1.2 The type-IIB supersymmetry rules 488
17.2 Type-IIB S duality 488
17.3 Dimensional reduction of $N = 2B$, $d = 10$ SUEGRA and type-II T duality 491
17.3.1 The type-II T-duality Buscher rules 494
17.4 Dimensional reduction of fermions and supersymmetry rules 495
17.5 Consistent truncations and heterotic/type-I duality 497

18 Extended objects 500
18.1 Generalities 501
18.1.1 Worldvolume actions 501
Contents

18.1.2 Charged branes and Dirac charge quantization for extended objects 506
18.1.3 The coupling of p-branes to scalar fields 509
18.2 General p-brane solutions 512
18.2.1 Schwarzschild black p-branes 512
18.2.2 The p-brane a-model 514
18.2.3 Sources for solutions of the p-brane a-model 517

19 The extended objects of string theory 520
19.1 String-theory extended objects from duality 521
19.1.1 The masses of string- and M-theory extended objects from duality 524
19.2 String-theory extended objects from effective-theory solutions 529
19.2.1 Extreme p-brane solutions of string and M-theories and sources 532
19.2.2 The M2 solution 533
19.2.3 The M5 solution 535
19.2.4 The fundamental string F1 536
19.2.5 The S5 solution 537
19.2.6 The Dp-branes 538
19.2.7 The D-instanton 540
19.2.8 The D7-brane and holomorphic (d = 3)-branes 542
19.2.9 Some simple generalizations 546
19.3 The masses and charges of the p-brane solutions 547
19.3.1 Masses 547
19.3.2 Charges 550
19.4 Duality of string-theory solutions 551
19.4.1 N = 2A, d = 10 SUGRA solutions from d = 11 SUGRA solutions 551
19.4.2 N = 2A/B, d = 10 SUGRA T-dual solutions 554
19.4.3 S duality of N = 2B, d = 10 SUGRA solutions: pq-branes 555
19.5 String-theory extended objects from superalgebras 557
19.5.1 Unbroken supersymmetries of string-theory solutions 559
19.6 Intersections 563
19.6.1 Brane-charge conservation and brane surgery 566
19.6.2 Marginally bound supersymmetric states and intersections 567
19.6.3 Intersecting-brane solutions 568
19.6.4 The (a1-a2) model for p1- and p2-branes and black intersecting branes 570

20 String black holes in four and five dimensions 573
20.1 Composite dilaton black holes 574
20.2 Black holes from branes 576
20.2.1 Black holes from single wrapped branes 576
20.2.2 Black holes from wrapped intersecting branes 578
20.2.3 Duality and black-hole solutions 586
20.3 Entropy from microstate counting 588
## Contents

### Appendix A  Lie groups, symmetric spaces, and Yang–Mills fields 591

A.1 Generalities 591
A.2 Yang–Mills fields 595
  A.2.1 Fields and covariant derivatives 595
  A.2.2 Kinetic terms 597
  A.2.3 $SO(n_+, n_-)$ gauge theory 598
A.3 Riemannian geometry of group manifolds 602
  A.3.1 Example: the $SU(2)$ group manifold 603
A.4 Riemannian geometry of homogeneous and symmetric spaces 604
  A.4.1 $H$-covariant derivatives 608
  A.4.2 Example: round spheres 609

### Appendix B  Gamma matrices and spinors 611

B.1 Generalities 611
  B.1.1 Useful identities 618
  B.1.2 Fierz identities 619
  B.1.3 Eleven dimensions 620
  B.1.4 Ten dimensions 622
  B.1.5 Nine dimensions 623
  B.1.6 Eight dimensions 623
  B.1.7 Two dimensions 624
  B.1.8 Three dimensions 624
  B.1.9 Four dimensions 624
  B.1.10 Five dimensions 625
  B.1.11 Six dimensions 626
B.2 Spaces with arbitrary signatures 626
  B.2.1 $AdS_4$ gamma matrices and spinors 629

### Appendix C  $n$-Spheres 634

C.1 $S^3$ and $S^7$ as Hopf fibrations 636
C.2 Squashed $S^3$ and $S^7$ 637

### Appendix D  Palatini’s identity 638

### Appendix E  Conformal rescalings 639

### Appendix F  Connections and curvature components 640

F.1 For some $d = 4$ metrics 640
  F.1.1 General static, spherically symmetric metrics (I) 640
  F.1.2 General static, spherically symmetric metrics (II) 641
  F.1.3 $d = 4$ IWP-type metrics 642
F.2 For some $d > 4$ metrics 643
  F.2.1 $d > 4$ General static, spherically symmetric metrics 643
  F.2.2 A general metric for (single, black) $p$-branes 644
  F.2.3 A general metric for (composite, black) $p$-branes 645
Contents

F.2.4  A general metric for extreme $p$-branes 646
F.2.5  Brinkmann metrics 647

Appendix G  The harmonic operator on $\mathbb{R}^3 \times S^1$ 648

References 650

Index 671
String theory has lived for the past few years during a golden era in which a tremendous upsurge of new ideas, techniques, and results has proliferated. In what form they will contribute to our collective enterprise (theoretical physics) only time can tell, but it is clear that many of them have started to have an impact on closely related areas of physics and mathematics and, even if string theory does not reach its ultimate goal of becoming a theory of everything, it will have played a crucial, inspiring role.

There are many interesting things that have been learned and achieved in this field that we feel can (and perhaps should) be taught to graduate students. However, we have found that this is impossible without the introduction of many ideas, techniques, and results that are not normally taught together in standard courses on general relativity, field theory or string theory, but which have become everyday tools for researchers in this field: black holes, strings, membranes, solitons, instantons, unbroken supersymmetry, Hawking radiation .... They can, of course, be found in various textbooks and research papers, presented from various viewpoints, but not in a single reference with a consistent organization of the ideas (not to mention a consistent notation).

These are the main reasons for the existence of this book, which tries to fill this gap by covering a wide range of topics related, in one way or another, to what we may call \textit{semiclassical string gravity}. The selection of material is according to the author’s taste and personal preferences with the aim of self-consistency and the ultimate goal of creating a basic, pedagogical, reference work in which all the results are written in a consistent set of notations and conventions. Some of the material is new and cannot be found elsewhere.

Precisely because of the blend of topics we have touched upon, although a great deal of background material is (briefly) reviewed here, this cannot be considered a textbook on general relativity, supergravity or string theory. Nevertheless, some chapters can be used in graduate courses on these matters, either providing material for a few lectures on a selected topic or combined (as the author has done with the first part, which is self-contained) into an advanced (and a bit eclectic) course on gravity.

It has not been too difficult to order logically the broad range of topics that had to be discussed, though. We can view string theory as the summit of a pyramid whose building blocks are the theories, results, and data that become more and more fundamental and basic the more we approach the base of the pyramid. At the very bottom (Part I) one can find tools
Preface

such as differential geometry and the use of symmetry in physics and fundamental theories of gravity such as general relativity and extensions to accommodate fermions such as the CSK theory and supergravity. The rest of the book is supported by it. In particular, we can see string theory as the culmination of long-term efforts to construct a theory of quantum gravity for a spin-2 particle (the graviton) and our approach to general relativity as the only self-consistent classical field theory of the graviton is intended to set the ground for this view.

Part II investigates consequences, results, and extensions of general relativity through some of its simplest and most remarkable solutions, which can be regarded as point-particle-like: the Schwarzschild and Reissner–Nordström solutions, gravitational waves, and the Taub-NUT solution. In the course of this study we introduce the reader to black holes, “no-hair theorems,” black-hole thermodynamics, Hawking radiation, gravitational instantons, charge quantization, electric–magnetic duality, the Witten effect etc. We will also explain the essentials of dimensional reduction and will obtain black-hole solutions of the dimensionally reduced theory. To finish Part II we introduce the reader to the idea and implications of residual supersymmetry. We will review all our results on black-hole thermodynamics and other black-hole properties in the light of unbroken supersymmetry.

Part III introduces strings and the string effective action as a particular extension of general relativity and supergravity. String dualities and extended objects will be studied from the string-effective-action (spacetime) point of view, making use of the results of Parts I and II and paying special attention to the relation between worldvolume and spacetime phenomena. This part, and the book, closes with an introduction to the calculation of black-hole entropies using string theory.

During these years, I have received the support of many people to whom this book, and I personally, owe much: Enrique Álvarez, Luis Alvarez-Gaumé, and my long-time collaborators Eric Bergshoeff and Renata Kallosh encouraged me and gave me the opportunity to learn from them. My students Natxo Alonso-Alberca, Ernesto Lozano-Tellechea, and Patrick Meessen used and checked many versions of the manuscript they used to call the PRC. Their help and friendship in these years has been invaluable. Roberto Emparan, José Miguel Figueroa-O’Farrill, Yolanda Lozano, Javier Más, Alfonso Vázquez-Ramallo, and Miguel Ángel Vázquez-Mozo read several versions of the manuscript and gave me many valuable comments and advice, which contributed to improving it. I am indebted to Arthur Greenspoon for making an extremely thorough final revision of the manuscript.

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This book started as a written version of a review talk on string black holes prepared for the first String Theory Meeting of the Benasque Center for Theoretical Physics, back in 1996, parts of it made a first public appearance in a condensed form as lectures for the charming Escuela de Relatividad, Campos y Cosmología “La Hechicera” organized by the Universidad de Los Andes (Mérida, Venezuela), and it was finished during a long-term visit to the CERN Theory Division. I would like to thank the organizers and members of these institutions for their invitations, hospitality, and economic support.